TECHNICAL REPORT LWL-CR-05P73

AUTOMATIC DISTANCE INDICATOR

by

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Final Report

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This report is the final technical report describing the development and test of the Automatic Distance Indicator (ADI).

The ADI is a man-carried, self-contained device that provides an accurate readout of distance travelled by walking personnel. The ADI automatically measures the distance of each step taken by the operator and reads out, in meters, an accumulated distance travelled.

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The device is intended to provide an accurate distance measurement (1% of distance travelled) for both special purpose applications or general utilization as a position location or navigation aid by foot soldiers.

Three ADI units were designed, fabricated and tested with funding from the US Army Land Warfare Laboratory under Contract DAAD05-73-C-0535. All contract objectives were achieved. The systems are scheduled for MASSTER tests at Ft. Hood during the 4th Qtr FY 74.

AD-779388

FOREWORD

This effort was sponsored by the US Army Land Warfare Laboratory, Advanced Development Division, Applied Physics Branch under the technical supervision of Carey L. Weigel. The project was designated 05-P-73, Automatic Distance Indicator.

The Automatic Distance Indicator program was a follow-on to the AN/PSN-7 Navigation System development in which the ADI concept was utilized for the distance input for a manpack navigator. The AN/PSN-7 development is documented in Technical Report No. LWL-CR-04P68 (AD 907156L).

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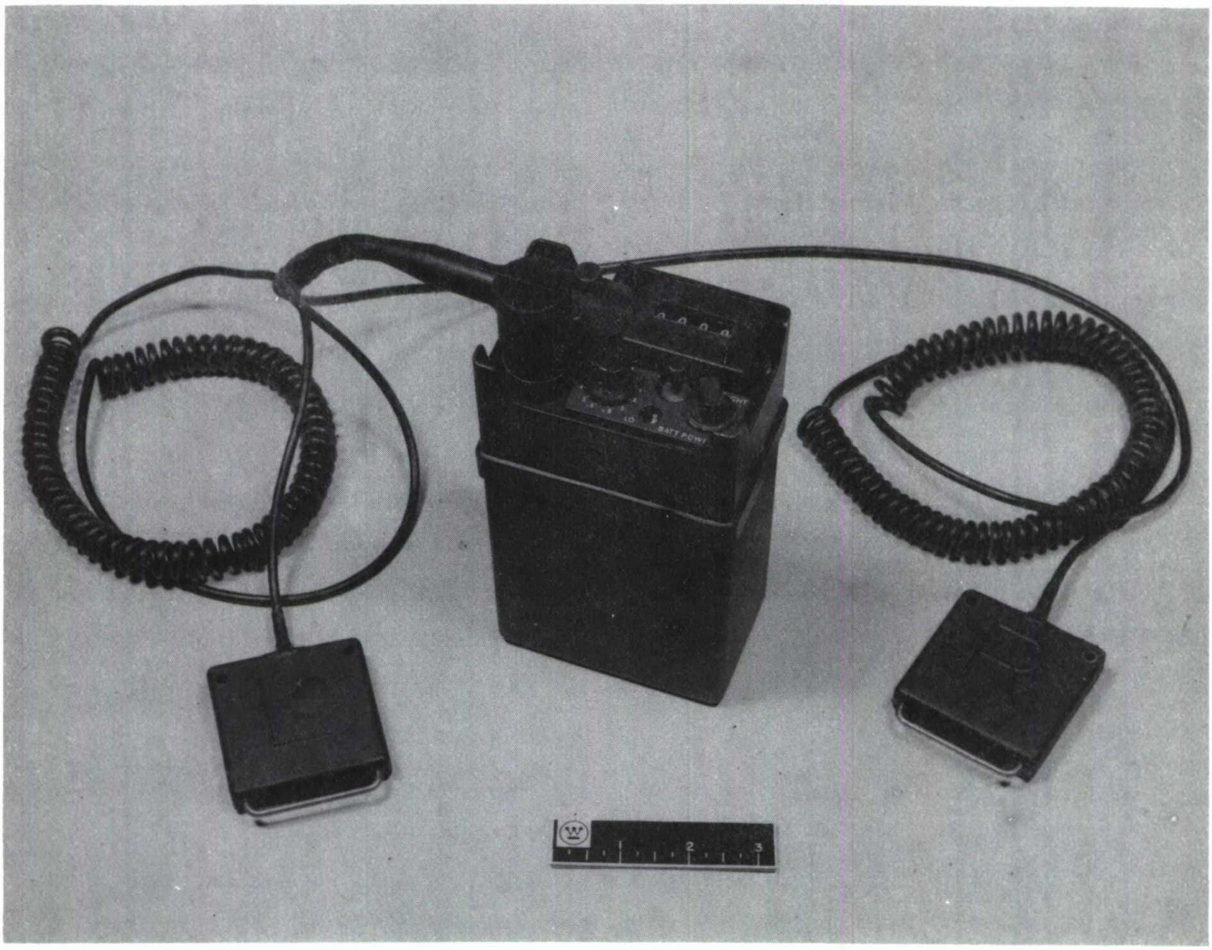

FIGURE 1-1. ADI System

1.0 SUMMARY

This report covers the design, fabrication and testing work done in Phase I and Phase II of the Automatic Distance Indicator (ADI) program (DAAD05-73-C-0535). The basic design and development of the Automatic Distance Indicator system utilized the operational concept and some basic circuit techniques developed before and during the AN/PSN-7 Land Navigator program under contracts DAAD05-68-C-0428 and DAAD05-71-C-0161. The purpose of the ADI program was to produce three prototype systems for MASSTER evaluation.

The ADI is an automatic distance indicating device designed as a compact unit to fit into a small arms ammunition case and which can be carried at the waist of a foot soldier in a tactical environment. The unit is completely self sufficient and utilizes no external signals. The ADI continuously displays the distance walked by the operator. This is accomplished by using two boot antennas to automatically measure the length of his steps. The signals to and from the antennas are respectively generated and processed to read out distance in meters as the operator walks.

The Land Navigator units upon which the concept and circuits are based were developed under sponsorship of LWL. The Navigator units have undergone extensive tests under varying field conditions including evaluation by MASSTER. The results of these tests demonstrated the soundness and reliability of the basic concept and design used as the basis for this program.

This report is concerned with the Study and Design work done in Phase I and fabrication, assembly and test work done in Phase II of the ADI program. The ADI was designed to meet the requirements as delineated for this program. The design addressed the problems of size, weight, battery life, and performance so as to best meet requirements and provide a reliable unit which would be convenient to use. The package was designed so that it would fit into an ammunition pouch and have all controls, readouts and connections accessible on the front panel of

the unit. Circuitry was designed to provide an accuracy of 1% and be of a form that is readily accessible for maintenance. Fabrication and assembly were carried out so as to maintain or enhance the features of the design to the greatest extent possible. Where changes were made from the design plan they were done to facilitate fabrication and improve the quality of the unit. The method of fabrication of the unit panel was changed from a sheet metal assembly to a machined part in order to provide a more precise and finished part. Particular care was given to fabrication and assembly of the high density printed circuit boards. Through the employment of printed wiring interconnecting wiring was minimized thus providing better reliability. The results of the design and fabrication effort was an ADI unit providing good performance and having the desired characteristics. A summary of the ADI characteristics is contained in the following list.

Size	2-3/8 x 3-11/16 x 6-1/4
Volume	57 cu. in., .033 cu. ft.
Weight	2-1/2 lbs.
Accuracy	1% of distance travelled
Resolution	1 meter
Maximum Range	9999 meters
Foot Step Range	11" - 44"
Low Battery Indication	Low battery warning indicator
Power Dissipation	.75 watt
Battery Life	14 hours

The refinements and modifications that were incorporated in the ADI as compared to the PSN-7 are the following:

1. Reduction in power drain in some circuit areas.
2. Some lower cost parts
3. More precise circuit operation
4. Some improved components
5. Simpler power supply
6. Better board adjustment provisions

7. Simpler logic and readout drive circuits
8. Pushbutton resettable readout
9. Larger display readout characters

In order to check and verify system performance during the program a complimentary test effort was carried out. The over-all test work during the program consisted of system, temperature and operational field tests. Both system and temperature tests were conducted in the laboratory using a simulated foot cross technique. This provided a good method to check performance at different step lengths and step rates. The results of these tests showed that when used with low temperature batteries the ADI would provide reliable operation for the range of step lengths over a temperature range of $-25^{o}F$ to $115^{o}F$. Field test results from walk tests made over a 200 meter course showed better than 1% performance for the three prototype units.

2.0 DETAILED DESIGN

The following paragraphs provide a detailed description of the ADI design.

2.1 System Design

Figure 2-1 shows a block diagram of the system design for the ADI. The basic electronic system is very similar to that of the PSN-7 Land Navigator. The boot antenna design is virtually identical to that of the PSN-7 with the exception of some refinement in the encapsulation. The electronic package is different though it is similar to the PSN-7 handset configuration. The ADI waist carried electronic unit will contain signal generating and processing circuitry to provide signals to and receive signals from the boot antennas. The boot antennas will be mounted on the operators feet, as shown in Figure 2-2, so that the length of the operator's footsteps can be measured. The step length signal from the receiver boot antenna is amplified, detected, compressed, thresholded, and scaled for direct readout on the panel of the unit. The electronic unit panel also contains the on and off switch and calibrating control as well as the distance readout and low battery indicator.

The operation of the ADI as illustrated in Figure 2-1 is as follows. The Automatic Step Length function consists of a transmitter whose function is to provide a highly stable 5 KHz reference level to the transmitter antenna mounted on the operators left foot, and a receiver, whose function is to amplify and process the induced voltage from the receiver antenna on his right foot. Five KHz is the frequency used and has been found to have low interference susceptibility and detectability at appreciable distances (10 meters) and a high predictability of the voltage distance function (approximately cubic).

The transmitter consists of two independent, but identical, driver circuits with automatic level control provisions. The transmitter signals are maintained in quadrature to each other by the system logic and are applied to two separate orthogonal

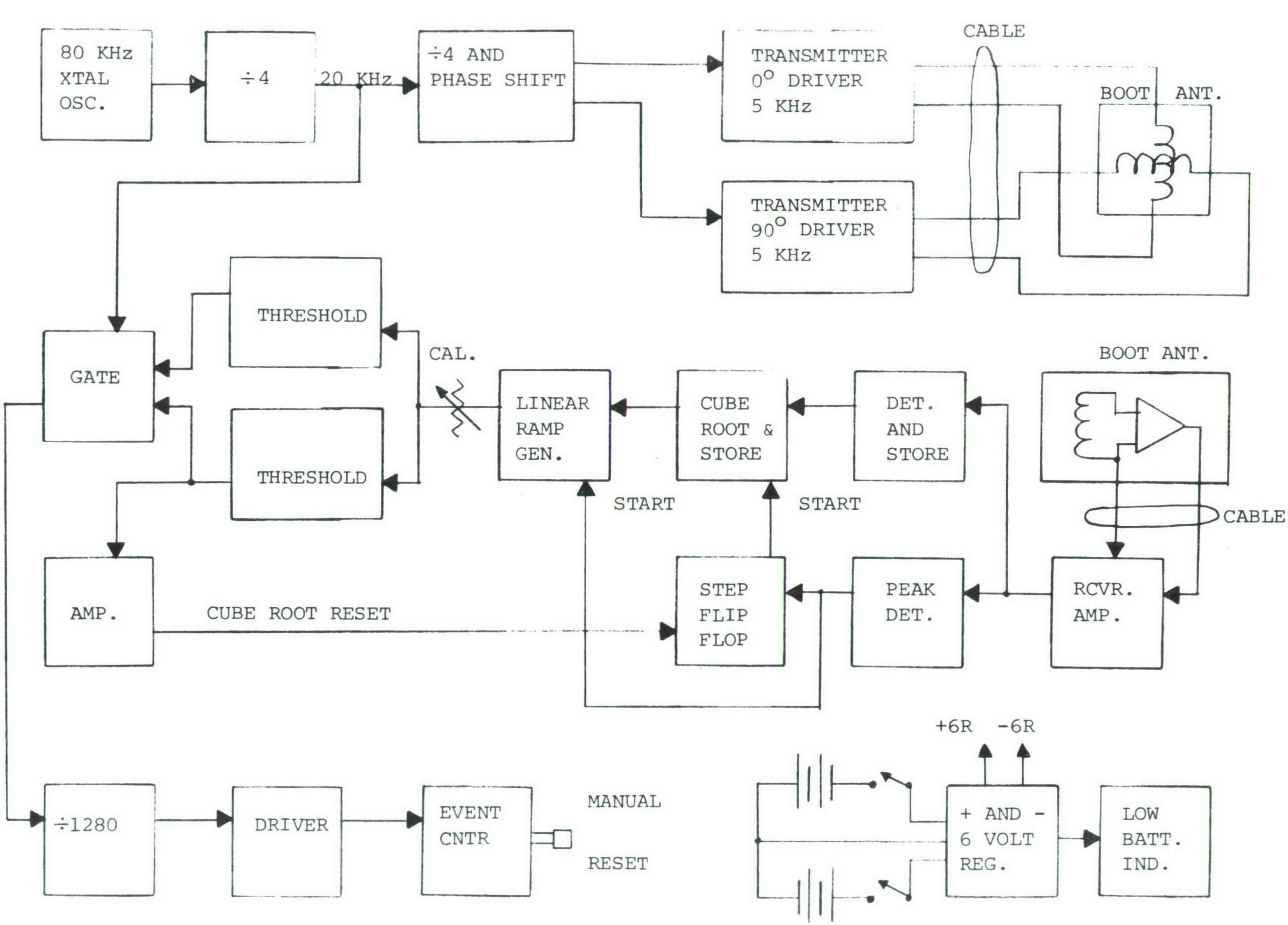

FIGURE 2-1. ADI System Block Diagram

FIGURE 2-2. Boot Antenna

solenoids in the boot antenna. The effect is to generate a rotating field that will induce a voltage in the receiver antenna that is independent of physical rotation of either antenna in the plane of the coils. This reduces the effect of foot rotation on the desired result.

The receiver, amplifies the induced voltage in the receiver coil and then processes it to extract and store the cube root of the minimum voltage occurring during each step. Two amplifiers are used, one in the boot antenna itself, and one on the Receiver/Cube Root PC card. Following the amplification the 5 KHz signal is envelope-detected, resulting in a voltage that varies from maximum to minimum as the feet move further apart. The minimum voltage occurring during one step cycle is stored to represent the maximum distance the feet were apart. Immediately after this happens, a slightly delayed peak detector triggers the foot-step flip flop which then tells the cube root circuit to process the cube root of the stored minimum. Thus, the envelope detector gives a voltage

$$V \propto \frac{1}{D^3}$$

where D is the foot separation distance. The minimum detector stores the minimum voltage during the step.

$$V_{1_{MIN}} = \frac{K_1}{D^3_{MAX}}$$

The cube root output is then

$$V_2 = \frac{K_2}{D_{MAX}}$$

where K_1 and K_2 are constants. This cube root output is stored until the foot-step flip flop is triggered again when the feet come together, at which time the cube root voltage is then converted to a precision ramp the slope of which is inversely proportional to the length of the step. The ramp is thresholded at two levels to create a gate. The time in the gate is then proportional to step length. The gate is used to start and stop a count of 20 KHz pulses for each step. The counts are scaled to 1280 per meter and fed into the readout driver circuit. A reset signal is generated from the gate and resets all the Receiver/Cube Root functions. This computer cycle reoccurs everytime the operator takes a step.

2.1.1 Detailed Design Description

The ADI system electronics circuitry is contained on 5 PC boards. These PC cards are the Transmitter PC board, the Receiver/Cube root board, the Processor board, the Power Supply board and the Mother board. Each of these is discussed in detail, referring to the schematics in the report.

2.1.1.1 Transmitter

The schematic of the transmitter is shown in Figure 2-3. This circuit will be contained on one PC board. The primary function of this board is to develop the stable 5 KHz signals to drive the boot transmitter antennas. In addition to the two coil driving circuits there is the count down logic which does the division of the Primary 80 KHz signal to 5 KHz and the 90° phase shifting to produce the quadrature relation between two transmitter signals.

Two separate, but similar, coil driver circuits are included on this board. One consists of Z4, Q1 and Q3 and their associated components, and the other, of Z5, Q2 and Q4. The operation of the two is similar with the exception of the input pulse to each and the polarity of supply voltage. Both pulses are 0 to 10 volts for 50 microseconds in duration (equal to 1/4 cycle of 5 KHz), but one is delayed in time by 50 micro-

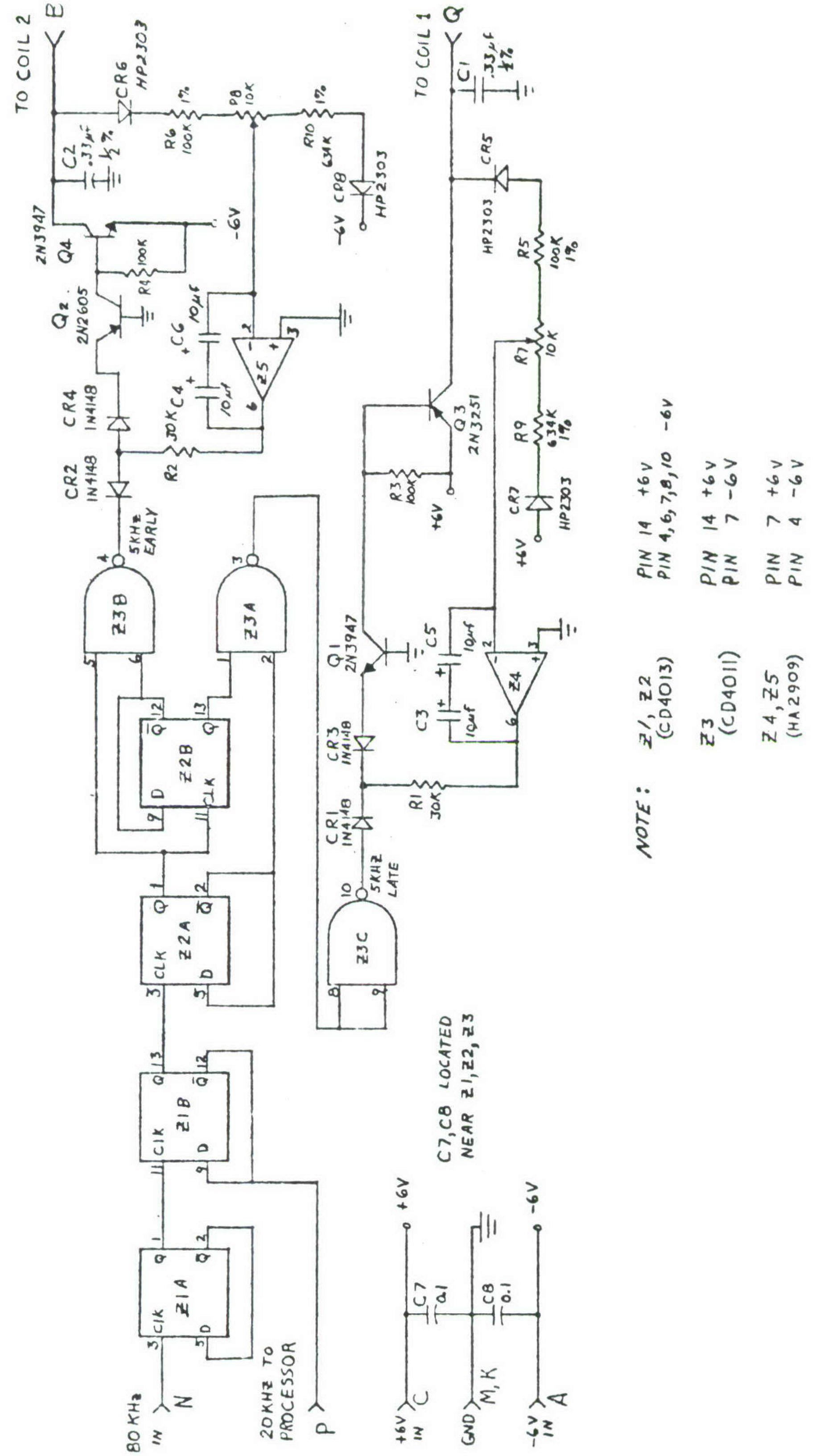

FIGURE 2-3. Transmitter Schematic

seconds so that the final outputs of the two transmitter drivers will be 90° out-of-phase with each other. This phasing provides the desired rotating field when applied to the orthogonal transmit coils. In the first transmitter driver, Q2 is switched off and on into saturation, pulling the output down to -6 V when the drive pulse is present at the cathode of CR2. When the drive pulse is present (+10 V), CR2 is off allowing Z5 to supply base current to Q4 through R2, CR4, and Q2. When the drive is zero, the base current is shunted away through CR2, turning Q2 and Q4 off. Thus the output transistor is switched off and on at the input pulse rate. C2 tunes the transmitter coil to 5 KHz so that the output voltage is a sine wave. The output level is held constant by controlling the amount of base current supplied to Q4 by the feedback loop associated with Z5. CR6 detects the signal and the divider consisting of R6, R8 and R10 compares it to the regulated -6 volt reference. Z5 amplifies the error to derive the base current. C4 and C6 filter out the 5 KHz components. The output level is fine adjusted to +3.25 volts peak positive by R8. The second transmitter driver operates in a similar manner except that this driver has the polarity of the supply voltage reversed from that of the first transmitter driver described above. In order to operate from this supply polarity the polarization sensitive components are also reversed.

The transmitter coil drivers are driven logic consisting of four binary dividers and the NAND gates. The first divider Z1 divides the primary 80 KHz stable source signal, from the power supply board, down to 20 KHz which is coupled out of the transmitter card to the scaling and driver card. The 20 KHz is then successively divided down to 10 KHz, and 5 KHz by Z2A, and Z2B respectively. The 10 KHz and 5 KHz are combined in NAND logic Z3A and Z3B to provide 5 KHz, 50 ms early and late pulses delayed by 50 ms. This is equivalent to 1/4 cycle or 90° of the 5 KHz signal. A diagram showing the relationship of the signals is shown in Figure 2-4.

2.1.1.2 Receiver/Cube Root

The receiver/cube root shown in Figure 2-5, consists of two stages of gain, an envelope detector, a minimum detector, a cube root circuit, and foot step flip flop circuitry. The first stage of gain, following the receiver coil, is contained in the receiver antenna package. The associated RC components shape the bandpass around the 5 KHz center frequency. The second stage of gain is Z3, again with bandpass shaping RC components. Z5 is the precision OP AMP envelope detector, removing the 5 KHz component and detecting the positive portion of the envelope. C8 is charged through the diode CR3 so as to track the signal at the positive input (pin 16 of Z5) until the signal goes negative. When this happens CR3 shuts off and C8 holds its charge, thus peak-detecting. The time constant of C8 and R12 is chosen to filter the 5 KHz component and yet allow C8 to track the envelope which varies as the feet separate. Z7, Q1, and their associated components form the minimum detector which detects the minimum positive value of the envelope. As long as the voltage at pin 22 is decreasing, Z7 charges C10 through CR4 in a manner so as to maintain the source of Q1 equal to the input. Once the minimum positive value has been reached the input will increase, causing Z7 to back bias CR4. C12 will then hold its voltage keeping the source of Q1 at the minimum voltage. Q1 is an FET to minimize leakage from C12. The path through CR5 and CR6 is a reset line which resets C12 to +6 V for the next step cycle after all the information has been processed. The stored minimum is applied through the voltage follower Z9 and the FET's Q2 and Q3 to charge C11 and C12. These are the cube root capacitors. Immediately after the minimum is reached and stored, the foot cross flip flop (Q6 and Q7) forward biases CR7 and pinches off Q2 and Q3. This allows C11 and C12 to discharge through R18, and R19 and Q4, respectively. When the charge on C11 reaches the threshold voltage, V_t, Z12 will switch Q4 off and stop the discharge of C12. The circuit time constants are

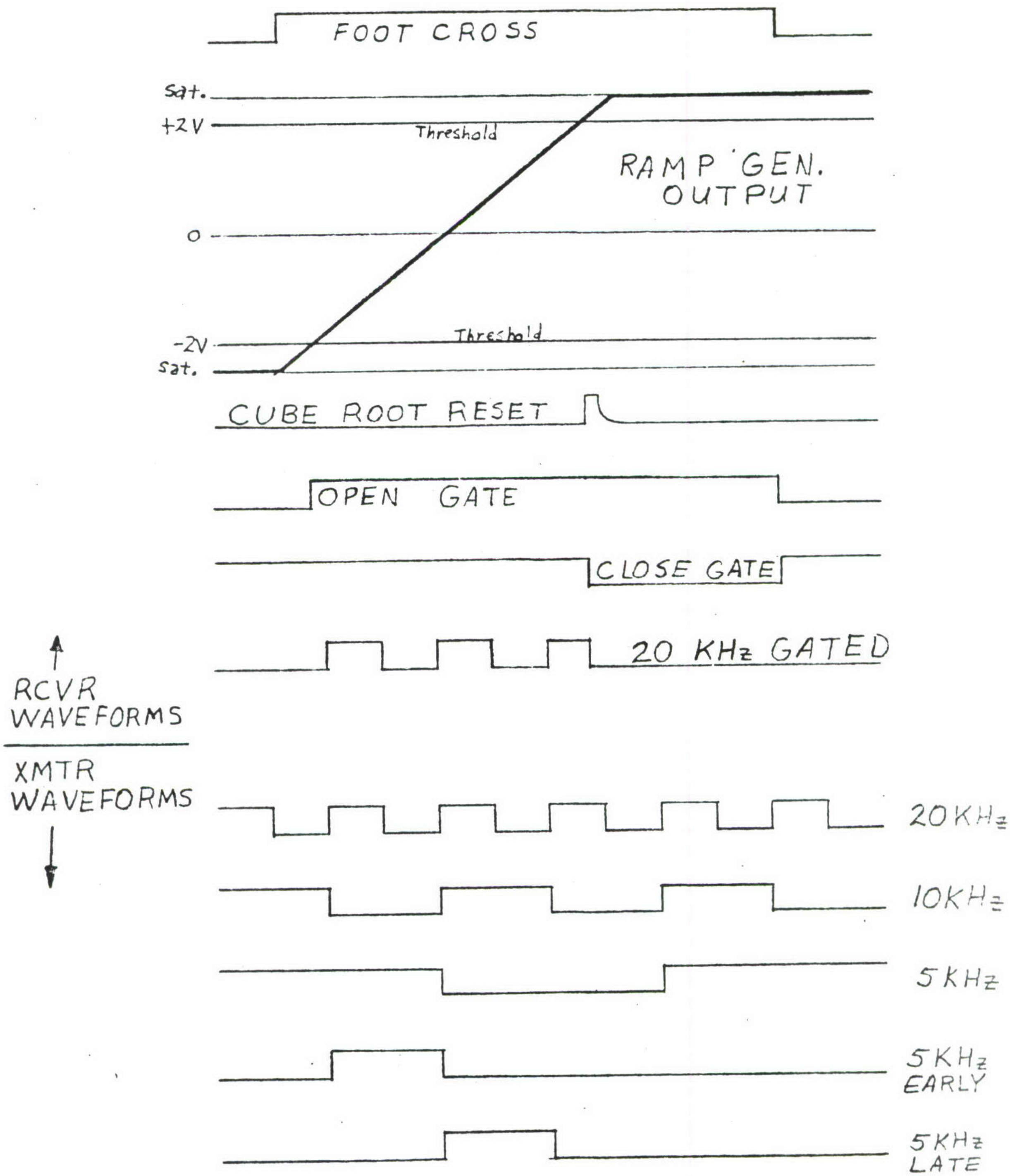

FIGURE 2-4. Signal Relationship

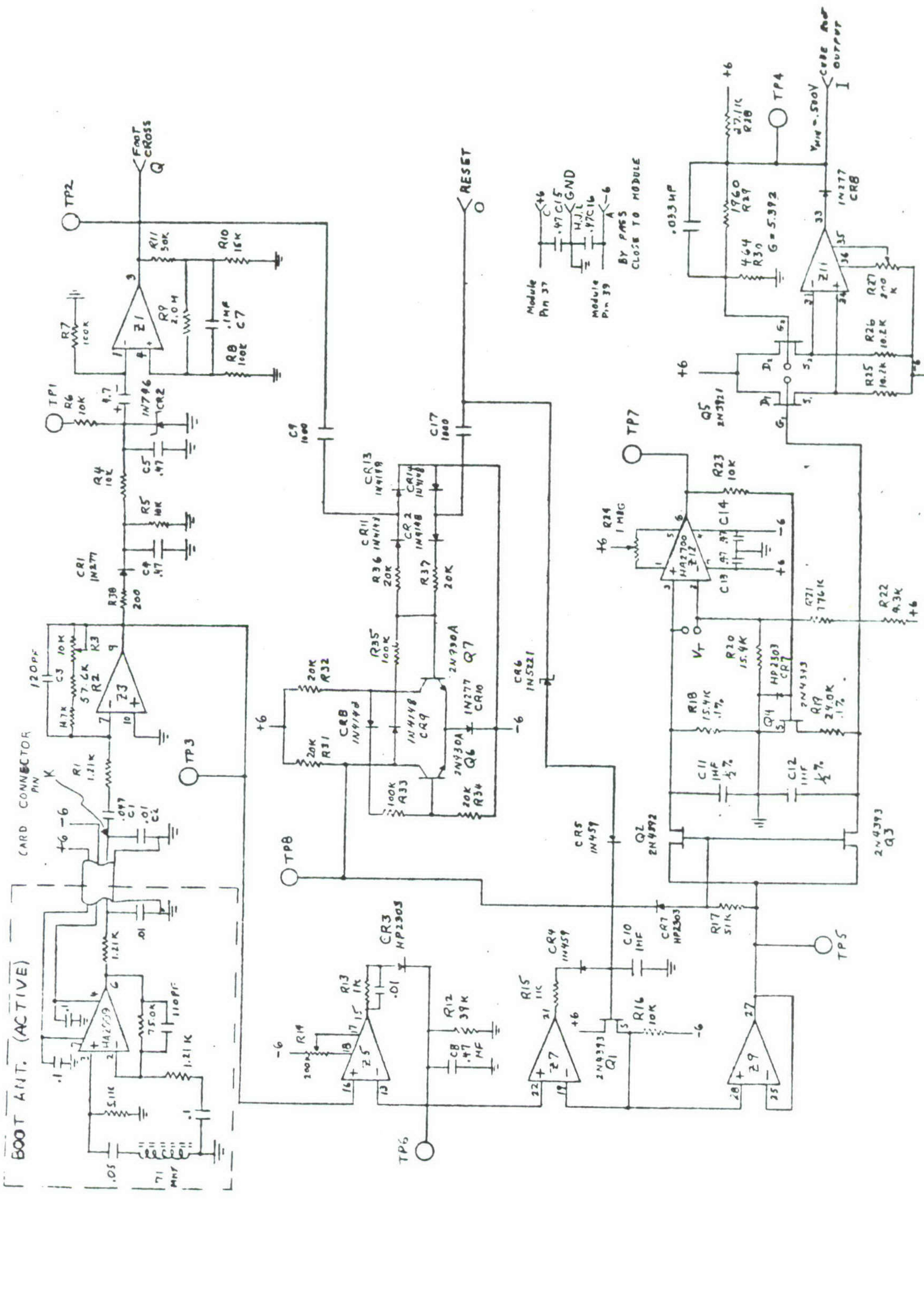

FIGURE 2-5. Receiver/Cube Root Schematic

selected so that the voltage left on C12 is the cube root of the initial applied voltage. (In actual fact, the precise root taken is 2.8. This value was selected to be different from the theoretical three because the near field effects of the solenoids in the boot antennas cause the induced voltage to actually follow a 2.8 exponent curve.) The last stage of the receiver is a gain and scaling stage and uses a dual FET input to minimize leakage and provide temperature tracking. The foot cross flip flop (Q6 and Q7) is triggered by the received signal through the latching OP AMP Z1. The received signal from Z3 is detected by CR1 and AC coupled to Z1. Any change in the polarity of the slope of the signal envelope will cause the latching OP AMP to switch if the latching threshold is exceeded. This happens at two points during the step: once, after the minimum has been stored, the slope changes from - to + and the OP AMP switches negative; again, after feet are brought together and begin to separate, the slope changes back and the OP AMP goes positive. Once the OP AMP switches, it is prevented from switching again until C7 discharges through R8. This gives the action a hysteresis that eliminates multiple triggering. The output of Z1, in addition to starting the cube root process, also triggers the logic portion of the system to process the final output. This occurs when Z1 goes positive.

The foot cross flip flop is reset by the system logic through C17 and its associated components. The reset signal also resets the minimum detector capacitor, C10.

2.1.1.3 <u>Processor</u>

Figure 2-6 shows the processing and readout driver circuitry. This board consists of a buffer with gain, a Howland current source ramp generator, a pair of thresholds, scaling logic and counter driver circuitry. The ramp generator is controlled by the foot cross signal which is coupled to the "hold off" transistor Q1 by Z4C. Z4C inverts the foot cross signal and drives the base of Q1 negative thereby turning Q1 off. This

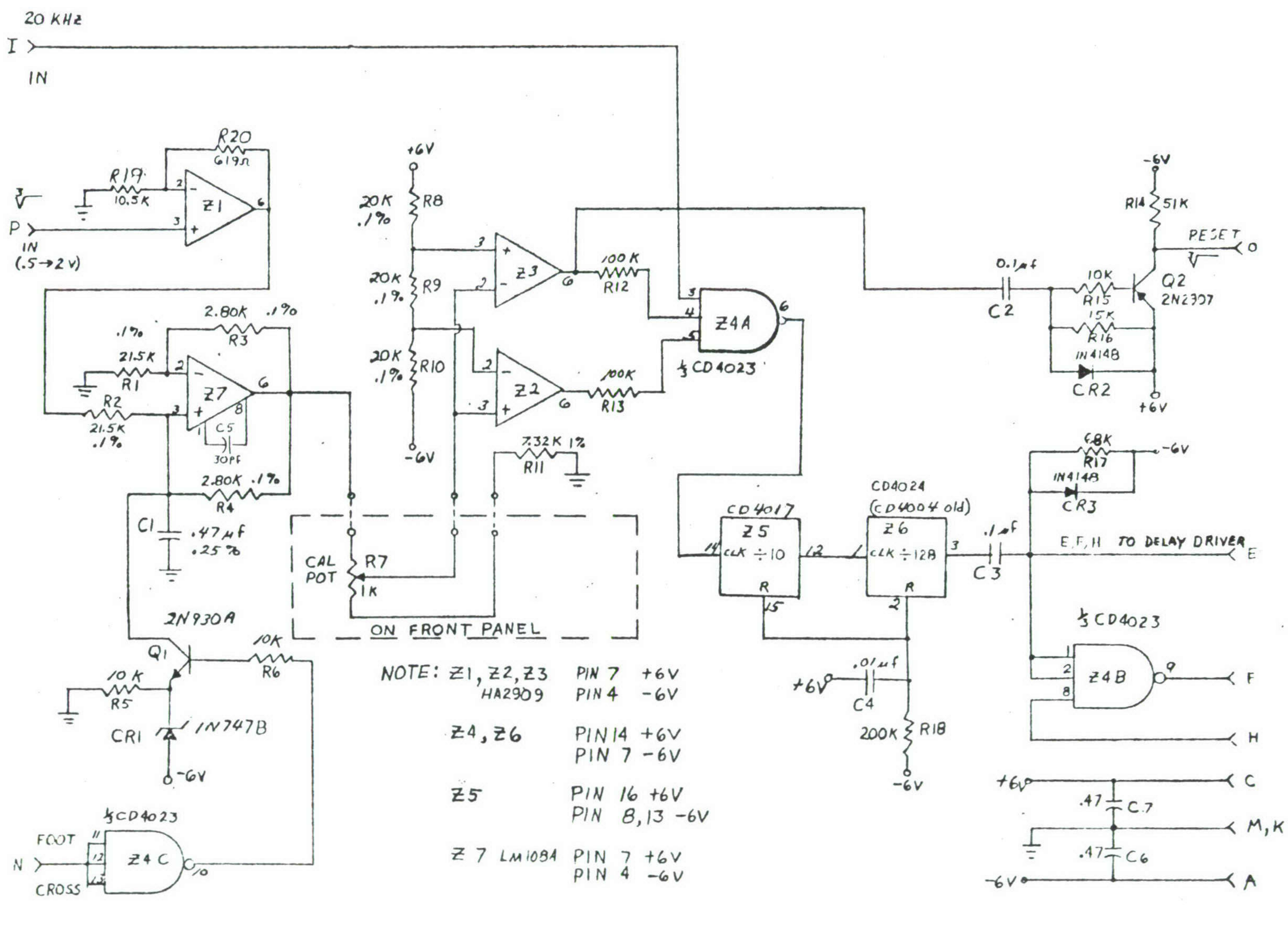

FIGURE 2-6. Processor Schematic

allows the ramp generator, consisting of Z7 with its associated components, to generate a linear ramp with a slope proportional to the stored cube root voltage that is connected to the ramp generator input. The ramp voltage is coupled through a calibration potentiometer R7 and then to two threshold circuits Z2 and Z3 with their associated resistors. These circuits function as a gate. Z2 is normally down and Z3 is normally up. The output of Z2 is driven up when the ramp reaches -2 volts whereupon logic element Z4A passes 20 KHz pulses to the divide by ten divider Z5. When the ramp rises to +2 volts the Z4A stops passing the 20 KHz pulses. This gating passes the number of 20 KHz pulses which is proportional to each step length. For a short step the ramp is steep and the time between thresholds is short. When the step is long the ramp rise rate is relatively low and the time between thresholds is long. Thus a long step gates a larger number of 20 KHz pulses. The gated pulses are divided down by Z5 and Z6 which divide by 10 and 128 respectively to count down the 20 KHz pulses by 1280. Each 1280 counts of the 20 KHz is equal to one meter of step length walked. The scaled pulses out of Z6 must be stretched and amplified to provide the proper pulse to drive the event counter readout.

Q2 in conjunction with CR2 and R14, R15 and R16 provide the reset signal for resetting the cube root circuits. The output of threshold Z3 is used for the basic reset timing signal.

2.1.1.4 Power Supply

The power supply PC board schematic diagram is shown in Figure 2-7. This board contains the processor driver delay circuit, the positive and negative 6 volt regulator circuits, the battery condition indicator circuit and the 80 KHz crystal oscillator. Because the electromechanical counter load can produce a significant voltage drop across the batteries it is necessary to delay its operation so there will be no chance of interference with the gate pulses. The battery voltage drop is in the form of 33 ms pulses which are produced each time the

counter is incremented. As the system batteries are expended their internal resistance rises and the pulses tend to increase. Since they could affect the operation of the Receiver Cube Root circuits during the processing, a design investigation was made to attempt to decouple the supplies. This investigation showed that sufficient decoupling to attenuate the pulses significantly below an interference level would require prohibitively large capacitors. An alternative approach was then developed. The approach developed and used was to delay the count pulses to a point in the step cycle when no processing was taking place. Since for steps greater than 1 meter, the counter may increment twice after some steps, a simple one shot delay would not be sufficient. Therefore a dual gated one shot delay circuit was designed that provides either one or two (whichever is required) output pulses after a fixed delay. The input pulse or pulses are then repeated with a 90 ms delay. The delay positions the counter pulses in time so that they do not interfere with any critical function.

The delay function is provided by two MC14528 dual COS MOS one shot IC's. Of the four one shots available in the two IC's three are used. These are Z7A, Z7B and Z8A in Figure 2-7. Z7A is connected to utilize the retriggerable capability of the MC14528 one shot circuits whereas for Z7B and Z8A retriggering is inhibited. For Z7A this means that although the timing starts after the input signal rises from its quiescent state, the output will be held on until the time out is completed should the input signal drop and then rise again before the one shot delay time out occurs.

Operation of the delay driver is such that if only one pulse is present, the Z7A delay time nearly coincides with that of Z7B and only a single pulse is generated by Z8A. Z7A, however, provides the delay timing for the second pulse if it is present. The two input gate, which is on the processor board, is connected to prevent a second pulse from retriggering Z7B hence, Z7B

delays the first pulse only. Complementary trigger capability of the MC14528 saves one gate and allows separate inputs from Z7A and Z7B to trigger Z8A so as to produce the 33 ms pulse required for positive operation of the readout. The output of Z8A is translated and buffered by Q9 and Q10 to drive the electromechanical counter readout.

Each of the two regulator circuits consists of a series pass transistor Q_1 and Q_2 driven in closed loop configuration by an amplifier using a zener diode to derive the input signal from the regulated bus. The zener diodes CR1 and CR2, for the +6 and -6 volt supplies respectively, drive the non-inverting input of the amplifiers Z1 and Z2. The inverting inputs of the amplifiers are connected to reference voltages through potentiometers R6 and R8 and resistors R7 and R9. The reference voltage for each supply is derived through the potentiometers from the regulated voltage of the supply of opposite polarity. The resistors and potentiometers divide the regulated reference voltage by approximately eleven to one and consequently any change in the regulated reference supply voltage, though unlikely, would be attenuated by more than 10 dB. The potentiometers provide for setting the regulated supply voltage to the exact supply level of 6 volts. The regulators will provide better than one per cent regulation for a battery voltage range, during discharge, of 8.5 volts to 6.9 volts.

The battery condition indicator circuit, which is on the power supply card, will drive an indicator to show four ADI battery power states. These states are: system power off; system power on with normal battery condition; system power on with low battery condition; and system power on with battery replacement required. The readout will be a mini indicator which utilizes a ruggedized 100 microampere microminiature meter movement. It uses a center zero type scale whereon the pointer bar which is normally in the center can be deflected 30° to the right or left

from the center. The various states will be indicated as follows:

Off 

On-normal 

On-low battery 

On-replace battery  oscillating position with step

The battery indicator circuitry in the power supply consists of Z3, Z4, Q3, Q4, Q5, Q6, Q7, Q8, CR3, CR4, CR5 and CR6 with their associated components. The circuit operates from the voltage drop across the series regulator transistors Q1 and Q2. For power on normal battery condition Q3, Q4, Q5 and Q6 will be on producing a negative output from Z3 and Z4. The negative output from Z3 and Z4 will drive the indicator to deflect to the right. When the battery voltage drops sufficiently, by discharging to the low battery condition, the voltage drop across either or both Q1 and Q2, depending upon which battery discharges first, is low enough to turn either or both Q5 or Q6 off. This will drive Z4 positive, deflect the indicator to the left and a low battery condition will be displayed. A further drop in battery voltage to the nearly discharged battery state will turn either or both Q3 and Q4 off thereby driving Z3 positive which turns on Q7. The indicator pointer will then move to center because current will be shunted to ground through Q7. When a foot cross signal turns on Q8 during each step Q7 will be turned off causing indicator deflection to return to the left position. Thus for the power on discharged battery condition ,the indicator will oscillate between center position and left position with each step. For the off position of the system the indicator will remain at the center position.

The 80 KHz crystal oscillator circuit is also on the power supply card. The oscillator uses the crystal as a feedback element for an op amp. An NT cut crystal is used. This cut has the features of low temperature drift and small crystal size. The crystal has a frequency accuracy of .01 per cent and a temperature drift variation of .01 per cent maximum.

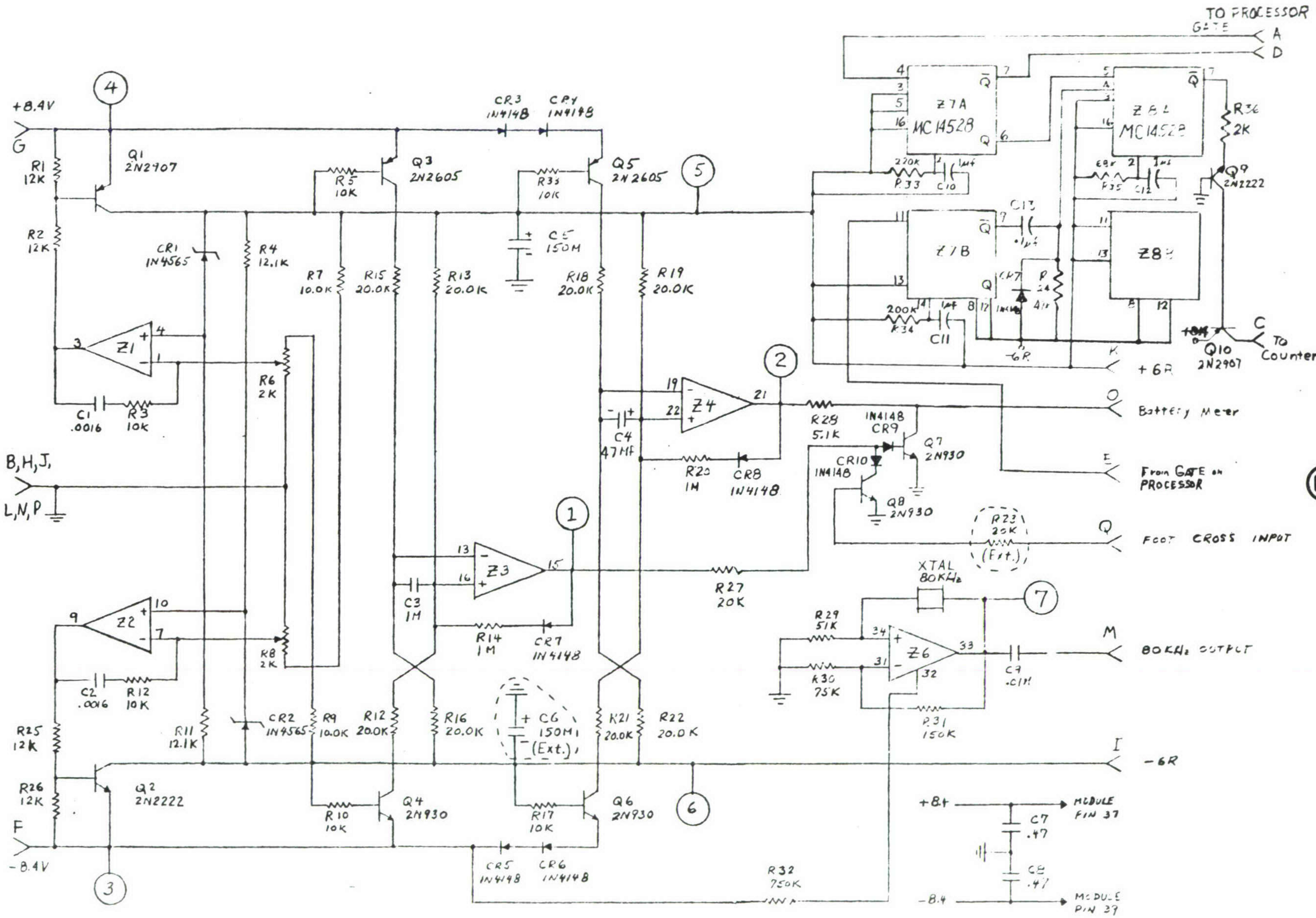

FIGURE 2-7. Power Supply and Delay Driver Schematic

2.1.1.5 Interwiring - Mother board

Generally interconnecting wiring in a compact unit, such as the ADI, is objectionable because it tends to be expensive and difficult to install in addition to using space inefficiently. In order to avoid these objections in the ADI printed circuit wiring was used where it was compatible. A printed circuit mother board was designed to interconnect the 4 circuit function PC boards of the unit. Four subminiature receptacle PC connectors are mounted on the board and interconnected by printed circuit wiring. The mother board also contains a few components that do not function for a particular board. These components are resistors for the panel illumination LED's and the transistors for system protection from reversed battery polarity. The interconnection board is mounted to the underside of the control panel and the board provides support for one end of the 4 PC boards. The opposite end of the boards are supported by a notched nylon grip which retains the board ends.

Interconnection between the mother board and the control panel components cannot be done well with PC wiring. This interconnection is best done with a small cable. The cable leads were connected to small terminals on the mother board at one end and to the terminals of the panel mounted components at the other end.

Figure 2-8 is a diagram of the ADI unit wiring.

2.1.2 Battery Selection

The requirement for high energy density of the battery supply in the ADI is a prime factor for battery selection. The requirement also exists for effective operation at low temperatures down to $-25^{o}F$. To meet these requirements a search was made for a suitable battery. The search and investigation showed that recently developed lithium batteries have good potential for meeting the requirements of the ADI system. They have a watt-hour capacity that is nearly twice that of a comparable mercury battery. Their low temperature operation extends below $-25^{o}F$

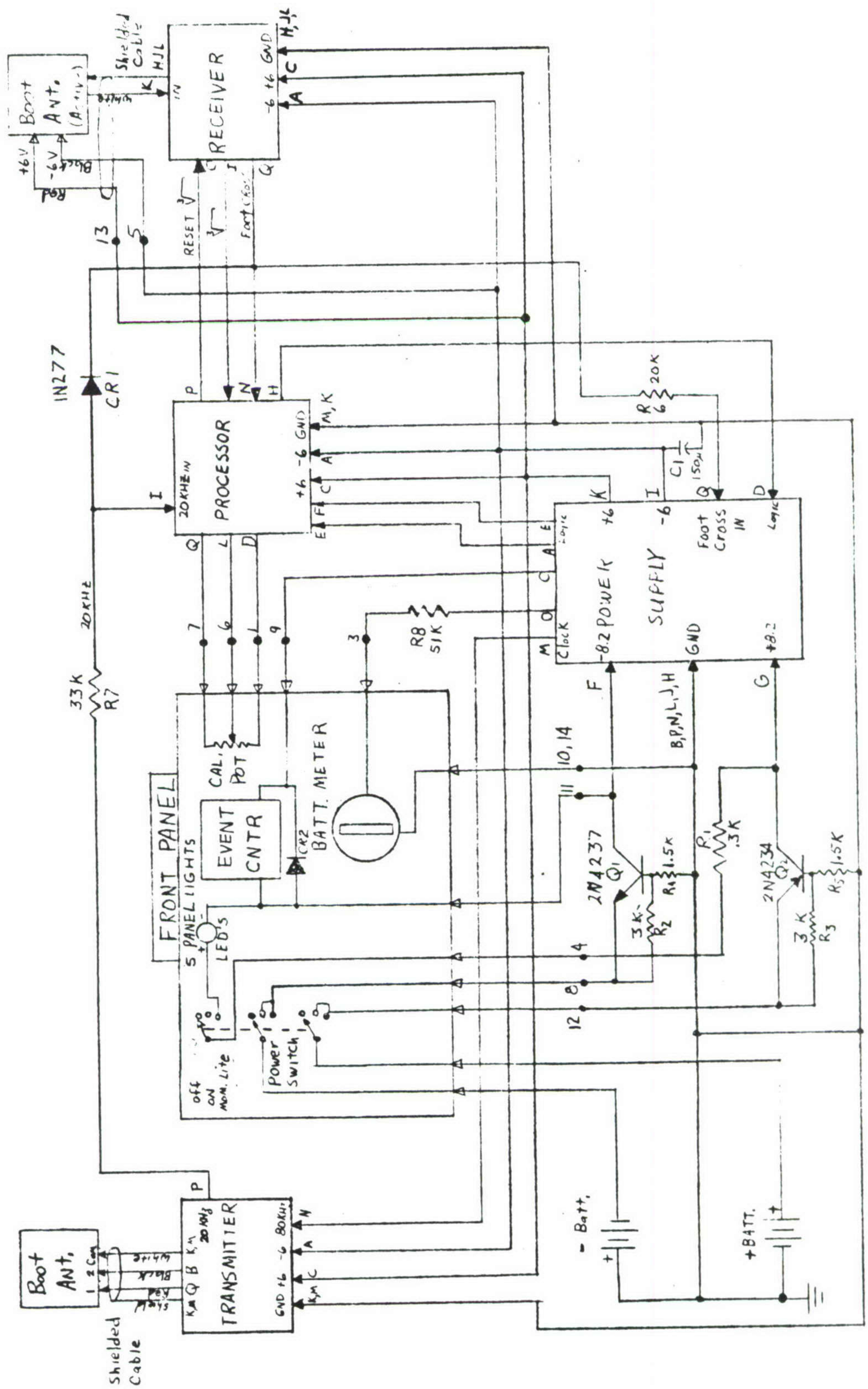

FIGURE 2-8. ADI Wiring

without the loss exhibited by mercury batteries. However, even though lithium batteries offer significant advantages over mercury batteries, they contain the active metal lithium, which presents a possible question of safety. Some additional time will therefore be required to establish these batteries as safe for use in personnel carried equipment. Although it is not possible to determine at this time when these batteries will be established from the safety standpoint some measurements were made on sample batteries in the event that they will be available soon. Provisions were also made so that a changeover to lithium batteries could be easily accomplished.

Because of the unknown time for complete acceptance of lithium batteries and the fixed schedule of the ADI prototype program it was necessary to design for a mercury battery supply with easy conversion to lithium batteries in the near future. The selection of the mercury battery size is constrained by the limited space available for them in a holder that will provide easy replacement. The available space limits the milliampere capacity to 1000 ma-hrs. for the nominal 8.5 volts required for proper circuit performance. The average load of the ADI on the battery supply will be about 50 ma. This load on a 7 cell battery will drop the voltage to the low voltage condition of 7.5 volts after about 14 hours which more than meets the minimum requirement at normal temperatures. At low temperature the capacity drops significantly, however the Mallory RMR-IN-CMC cell has been selected because it provides the best low temperature capability in a mercury battery of this size. Expected life at $0^{\circ}F$ will be 4 to 6 hours at $-25^{\circ}F$ life will be 2 to 3 hours.

Two batteries will be required in an ADI unit one for positive supply and one for negative supply. Each battery will be a 7 cell stack and its size and weight will be 0.66 inches diameter by 4.55 inches long and 3.4 ounces. Even though the cell size which will be used is available assembled in stacks for Military types, the Military types do not include a 7 cell

stack. A 6 cell battery could not provide adequate voltage for proper circuit operation over the life of the battery. An 8 cell battery would be too large to package.

2.2 Mechanical Design

Introduction

A comprehensive mechanical design for the ADI was undertaken during Phase I. The criteria used to develop the mechanical design were based primarily on priorities indicated in the specifications which include performance, size, weight, ease of operation and maintenance, reliability and productivity. Additional customer preferences arising as the design developed were also included. The environmental requirements for the ADI require a well sealed, shock resistant temperature tolerant unit. The unit should be waterproof, withstand dropping and operate over a range of temperature.

The ADI package has been designed with careful attention to sealing it against water and to ruggedness for shock resistance. Circuitry has been designed to minimize the effects of temperature change.

The mechanical design utilizes development done on the AN/PSN-7 program. The panel illumination and control design incorporates the basic configuration which have been satisfactorily used on the PSN-7 handset panel. The battery contact design which has been successful on the PSN-7 has been used here.

The necessary package layout work was done to determine the most satisfactory arrangement of components. An aluminum mockup was made using the layout information. Parts were assembled to the mockup to provide a check for positioning and fit of components. By this means a more effective determination of the best position of controls, readouts and connectors was possible.

Battery holder design was done so as to hold the largest battery that could be accommodated. Since battery life in compact equipment is almost always less than ultimately desired the battery holder has been designed so that newly developed and im-

proved batteries coming into use could be used in place of mercury batteries.

2.2.1 ADI Package

The ADI package is basically a rectangular package with the control panel on the top. The package dimensions are 3-11/16" wide x 2-3/8" deep by 6-1/4" high. The volume is .033 cubic feet and the total unit weight is 2.5 pounds. A drawing of the unit is shown in Figure 2-9. The package is designed to fit into a standard small arms ammunition pouch which is carried at the waist. Figure 2-10 shows an ADI unit in an ammunition pouch. When carried in this manner some modification of the pouch cover may be desirable. This may be done by changing the hinge position of the cover to be on the side of the pouch. This would allow the cover to be moved to a position where it would be completely out of the way when reading the counter or making control settings on the panel.

The ADI package contains the five P.C. boards (four circuit boards and one interconnection board) the battery holder, and the control panel.

2.2.2 Can Design

The rectangular package design calls for a can fabricated of 1/16" aluminum. The can is in two sections. The upper section is the cover and panel with all of the components and circuit boards mounted on it. The lower section is the longer portion of the can which encloses the components mounted to the back of the panel. When closed the two sections are joined with an "O" ring seal between them. Two screws on the panel and threaded into pads welded to the inside of the lower section compress an "O" ring seal so as to seal the joint between the cover and lower can section.

The sides of the cover and the can were first fabricated as a one piece rectangular tube. The rectangular tube was cut into two sections; a short one about two inches long was used to make the sides of the cover and a long one about four inches long was

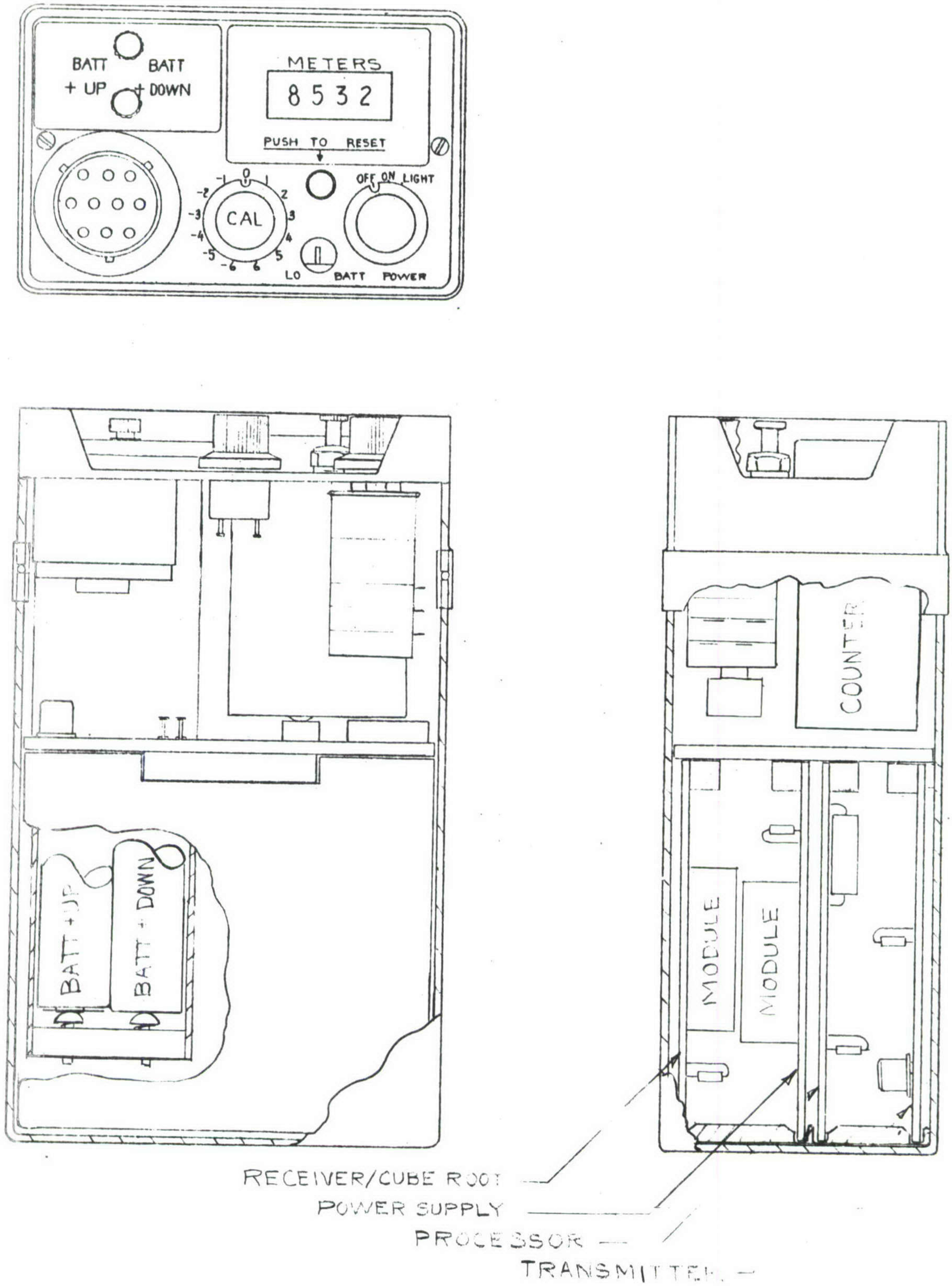

FIGURE 2-9. Drawing of ADI

FIGURE 2-10. ADI Unit in an Ammunition Pouch

used to make the can. Cutting the two sections from one piece insured a good fit between the can and cover. An aluminum rim was made to fit over the edges of the cover and can so that they could be joined with an "O" ring seal. The rim has grooves for the cover and can to fit into. The cover permanently inserted into one groove and the other groove holds the "O" ring for the can to seal against.

2.2.3 Panel Design

The basic panel, as a part, was the single most intricate non-electrical piece of fabrication in the ADI unit. An unassembled panel is shown in Figure 2-11. For the prototype systems the panel was machined from solid aluminum stock. This provided a panel with the dimensional accuracy required for dip-brazing it as part of the upper case assembly. The assembled panel which is on the top of the unit contains the power switch and calibrate controls, the readout counter with a reset button, the battery indicator, the battery replacement access cover and the quick disconnect connector for the boot coils. The panel arrangement is shown in Figure 2-12. The power switch is a three position on/off rotary switch with a momentary position for illumination of the panel when desired. Illumination of the panel is provided by five red LED's. Two LED's are used to illuminate the counter and are contained within the counter and the other three LED's illuminate the other panel functions. These other panel functions are the on/off switch, the calibration control and the battery condition indicator. The calibration control is a precision potentiometer. The battery condition indicator is a micro miniature meter. The counter is a 4 digit miniature counter with 3/16" high characters. A counter with large characters has been selected to provide the best possible readability within the constraints of space. A sealed push-button is located directly below the counter for resetting the counter.

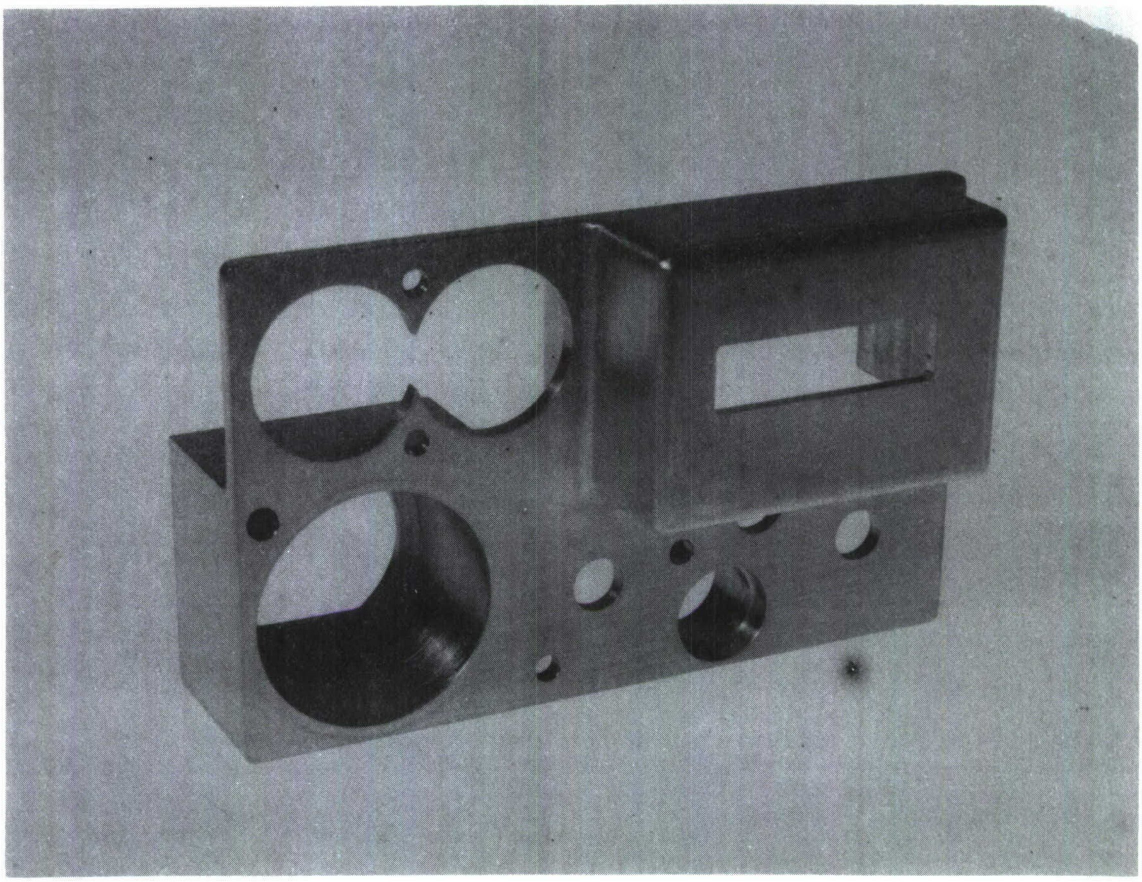

FIGURE 2-11. Machined ADI Panel

FIGURE 2-12. ADI Package Showing Panel

Access for battery replacement is through the panel. The design provides for a lanyard restrained cover at the upper left corner of the panel. The cover closes the two battery tubes which hold the batteries and can be easily opened for battery replacement. The cover closes against the panel surface which is attached to the tubes and provides a mating surface for the cover. A neoprene rubber gasket is attached to the cover, and provides a seal when the cover is screwed down to compress the gasket. The lower ends of the battery tubes have spring contacts to make connection to the batteries and are also sealed to prevent water that enters the battery compartment from entering the inside of the ADI package. The upper ends of the batteries are connected to ground through contacts on the cover which is electrically grounded through the hold down screws and the wire lanyard.

The connection to the boot coils is made through a ten pin miniature circular connector with a quick disconnect bayonet coupling. The female connector is mounted in a recessed hole in the panel. The connector is recessed in order to minimize the height of the mating male connector above the panel. An "0" ring seal is used to seal the connector to panel joining parts. The connector cable is attached to the male connector through a molded rubber type right angle fairing. By using a right angle bend the height of the connector assembly is kept as low as possible. The cable leads over the left edge of the panel and then downward.

The calibrate control and on-off switch are located at the bottom center and bottom right of the panel. These positions provide the best access to the controls on a small panel such as this. The knobs are aluminum and shape coded for differentiation under conditions requiring identification by touch.

Guard edges for the panel are located at the corners and along the back to protect the panel in the event that the unit is dropped or struck.

2.2.3.1 Power Switch

The on-off and panel light switch is a miniature enclosed three position rotary switch. The panel LED lights are turned on by a full clockwise momentary position of the switch. The rotary action requires a 30^{o} angular turn between positions of off, on and light. The switch has a through panel threaded bushing. The bushing is held in place with a seal nut threaded on to the bushing. The seal nut seals the bushing and shaft for the rotary motion.

2.2.3.2 Readout Display

A study of alternative types of displays for readout was made. The candidate readout display systems which were considered were motor driven counters, LED numeric, and event counters. Since the advantage of a motor driven counter, the capability to be slewed to a specific position, is a feature not required for the ADI and the disadvantages of relative complex electronics and the lack of a quick zero reset capability, this type of readout was considered as not compatible with ADI requirements. The use of an LED readout display would have the disadvantage of requiring a non-volatile memory as well as having limited readability in high light levels such as daylight. These considerations turned the attention to using a resettable event counter. Two sizes of resettable event counters were commercially available which could possibly be used in the ADI. The smaller unit, though small in size, was difficult to read because of small numerals (.075" high). The larger counter had 3/16" high characters which were easy to read and the counter would fit into the package. Figure 2-13 shows samples of the two counters placed side by side for comparison. The use of an event counter also has relatively simple electronic drive requirements. The preceding considerations in addition to the fact that the event counter costs would be lower favored the use of a size that would be easy to read.

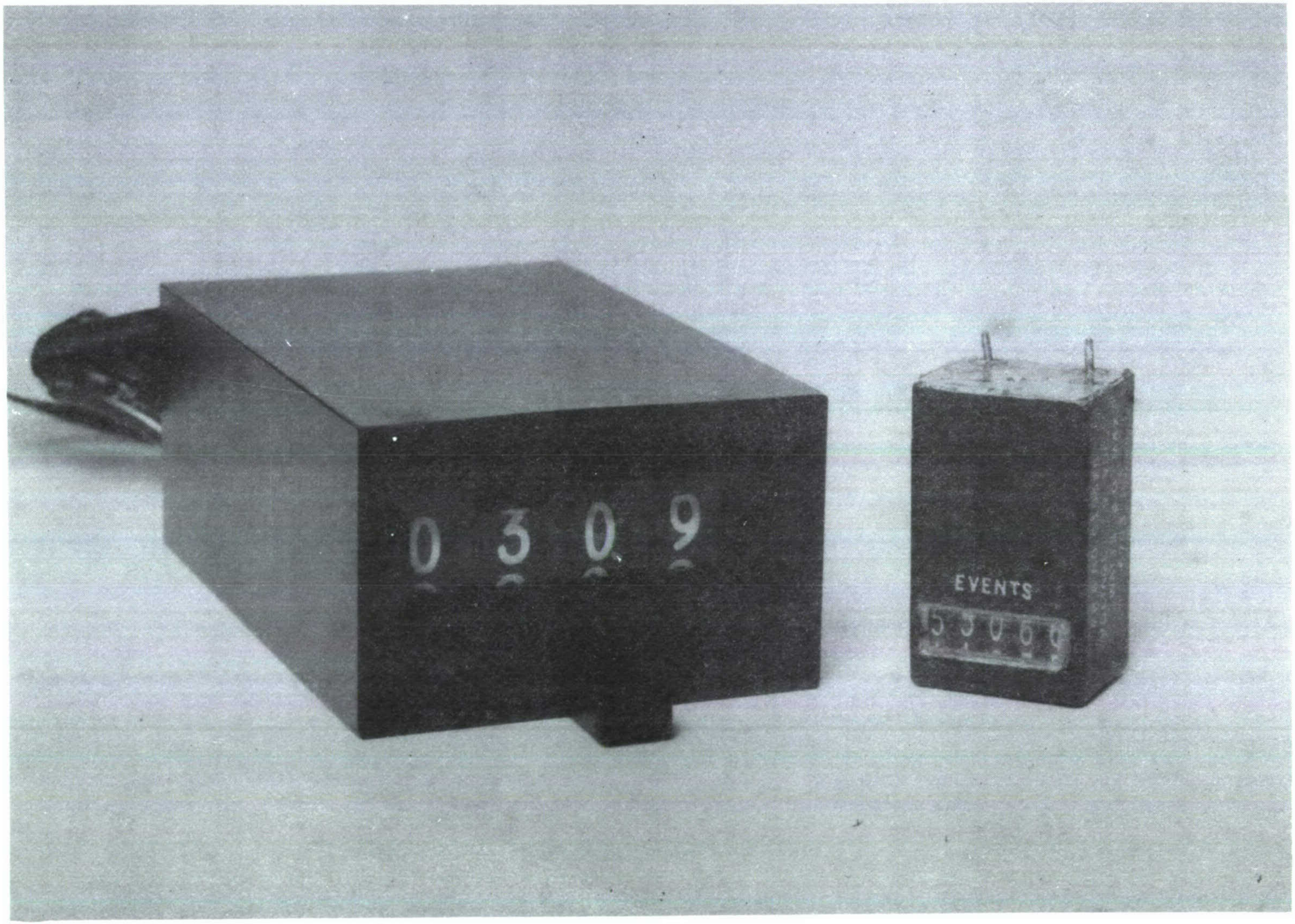

FIGURE 2-13. Comparison of Event Counters

2.2.3.3 Battery Holder

The battery holder holds two 0.65 inch diameter by 4.5 inch long batteries. The battery holder assembly is made of two pieces of .040" by .75" OD aluminum tubing. The two pieces of tubing are assembled into holes in the panel so they are flush with the surface. The tubing is held by dip-brazing. The holes through the panel and into the tubing provide for the insertion of batteries. The batteries are held in by a cover which will have two stainless steel contacts to connect the upper end of the batteries to ground. The opposite end of the battery tubes will have a micarta plug sealed in them. Each plug will have a spring contact in the center for connection to the battery.

2.2.4 Boot Units

2.2.4.1 Coils

Because small size for the boot units it desirable the foot coil design from the AN/PSN-7 was reviewed from the standpoint of size reduction. The results indicated that any reduction of the coils in length or area would reduce the level of the received signal. Unless the reduced signal level was compensated for by greater transmitter power the system would be subject to increased interference from other signals. Increasing the transmitter power, however, is undesirable because it would contribute to increased battery power drain. The relatively small battery power available in the ADI dictates designing for lower power drain. Increasing transmitter power could also contribute to interference with other ADI equipment operating in the area. Some degree of tradeoff also exists between coil size and operating frequency. Increasing frequency will tend to compensate for a lower signal level resulting from reducing coil size. Even though increasing frequency will tend to maintain signal levels experience has shown that it also increases the system susceptibility to interferring signals. This difficulty is compounded by problems of maintaining isolation between circuits within the unit at higher frequencies. Because the tradeoffs are not favorable

ones for a small low powered portable unit such as the ADI it was concluded that any size reduction would best be considered only from the standpoint of reducing the thickness of the coil assembly potting.

2.2.4.2 Cables

The interconnecting cable between the ADI unit and the boot units is basically two cables. These cables start together at the connector and are separated just below the waist so as to run down each leg to the boot coil units on the operators ankle. There is only one connector to connect the boot units to the electronic package. The two cables join at the connector in a molded neoprene faired junction to seal and strain relieve the cables. The cables enter the potted foot coils through a fairing for strain relief and are sealed by the potting compound. Each cable has a coiled stretch cable for easy conformity to position and motion of the operator.

2.2.4.3 Potting

Potting of the boot coil units has some critical requirements. The potting must provide essentially complete protection for the coil assemblies. It has to seal the assembly from moisture under conditions of prolonged exposure to water to the extent of complete immersion. The potting must not absorb moisture to any significant extent as well as seal out the moisture at cable entrances. In addition the location of the boot units exposes them to striking hard objects encountered while walking. The potting material is therefore required to be highly resistant to impact and abrasion. Electrically the material must have a high cubic resistance so as not to appreciably shunt the higher circuit impedances of the receiver amplifier.

The results of a review of potting material and methods showed that the polyurethane material offers the best properties overall. Its strength, resistance to shock and stability of electrical characteristics in the presence of moisture make it

a good material for the ADI foot coil potting application. The critical aspects appear to be centered around the procedure and care in preparing and doing the potting. Since the potting of the foot coil units and the connector cable junction at the opposite end of the cable are done by an outside vendor the materials and processes are specified to them. The vendor processes and capabilities were reviewed carefully to assure attention to the requirements of good potting.

3.0 TESTING

ADI testing consisted of essentially three phases. These were design and system testing in the laboratory, temperature testing and operational testing. Each of these areas is described in the following paragraphs.

3.1 System Test

System test was done, in a laboratory screen room, on the brassboard system and the three prototype systems. The test was set up so that the range of step lengths and rates could be readily simulated in order to measure the performance under well controlled conditions. The test set up is shown in Figure 3-1. The foot coils could be set at any desired step length by separating them on the bench and positioning them away from any sizable metal objects. The foot-cross was simulated by connecting the output of a square wave generator to the input of the foot-cross circuit in the receiver cube root. A counter was used to measure the counts produced in the processor with each step and also to accumulate output counts as a check on the readout counting when needed. Voltage adjustable power supplies were used to simulate battery voltage variation with use. Operation with the regular system batteries was also checked during the test. An oscilloscope was used to check voltages, gains and waveforms of the circuits to confirm proper operation.

Data taken showing accuracy capability of the system over the range of step length indicated good accuracy with some variation at the extremes. Over the principal range of operation the accuracy was within 0.3% and was better than 1% over the whole range. A plot of this data is shown in Figure 3-2.

3.2 Temperature Test

The performance of the ADI system was investigated over a range of temperatures. The ADI brassboard unit was used for temperature tests conducted in the environmental laboratory. A Murphy and Miller Altitude and temperature chamber with a temperature range capability of $-73^{\circ}C$ to $+93^{\circ}C$ was utilized. A diagram of the test set up is shown in Figure 3-3.

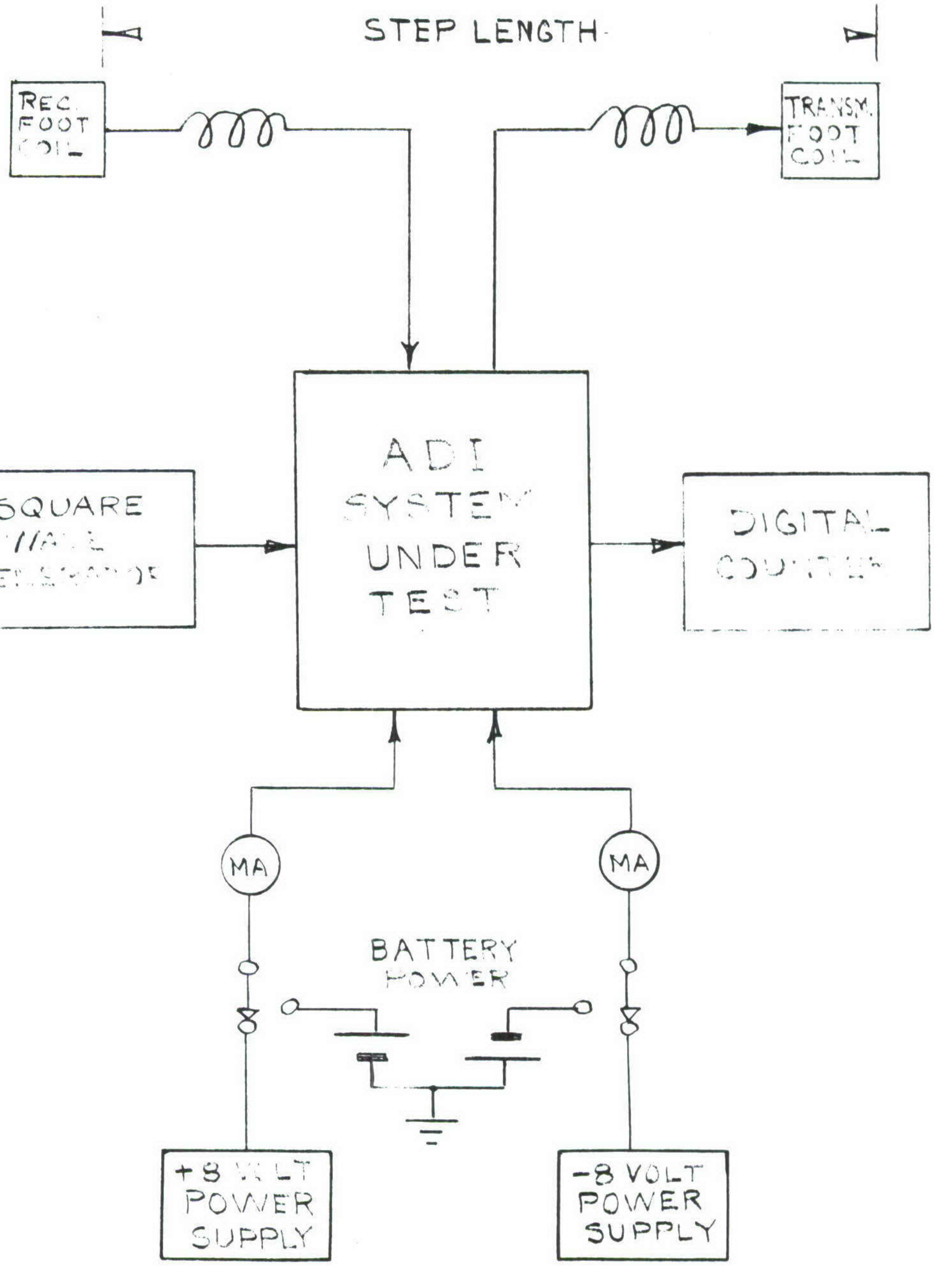

FIGURE 3-1. System Bench Test Set up

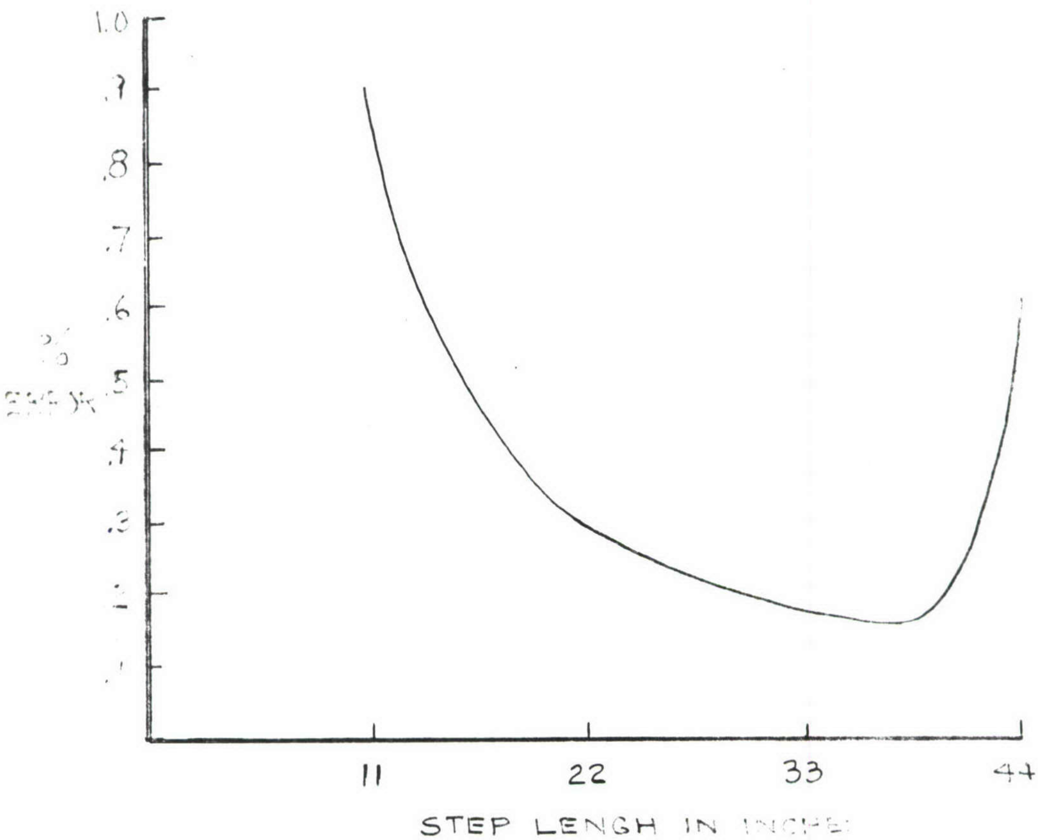

FIGURE 3-2. Plot of Percent Error vs Step Length

The brassboard electronics assembly was mounted in an open chassis. The chassis had terminal posts installed in the sides to facilitate connections to the various points in the unit for power, signal monitoring and signal injection. The system readout counter was also in the chamber and was placed in a position so that it could be seen through the window of the chamber. The calibration control was also placed in the chamber. The mercury batteries for system power were placed outside of the chamber since it is known that they would very likely be the limiting component at very low temperatures. The foot coils were also outside. They were attached to a wood mounting plate placed in the proximity of the chamber. The foot coils were mounted this way so that they could be positioned at a predetermined fixed distance from each other and also located away from large metal masses which could adversely affect the system accuracy if they were near. A temperature probe was used in addition to the chamber ambient temperature indication. The probe sensor was attached to the open chassis near the brassboard unit. The temperature readout was external to the chamber as was the other test equipment used in the test.

To simulate the foot cross signal a low frequency square wave generator was used. As shown in Figure 3-3 the square wave generator was connected to the ADI through a presettable counter. This connection provided control of the number of square waves that were fed to the ADI unit under test. The counter could be set to interrupt the square wave signal after the desired number of foot crosses had occurred. This provided a repeatable set of input conditions so that any change in output readout with changes in temperature could be easily observed. The foot coils were set at 22 inches separation for most of the test runs. Some runs were made at other separations to confirm that results did not vary with step length.

The temperature runs were made at a number of temperature points in the range of $-25^{\circ}F$ to $+115^{\circ}F$. The first runs showed that the

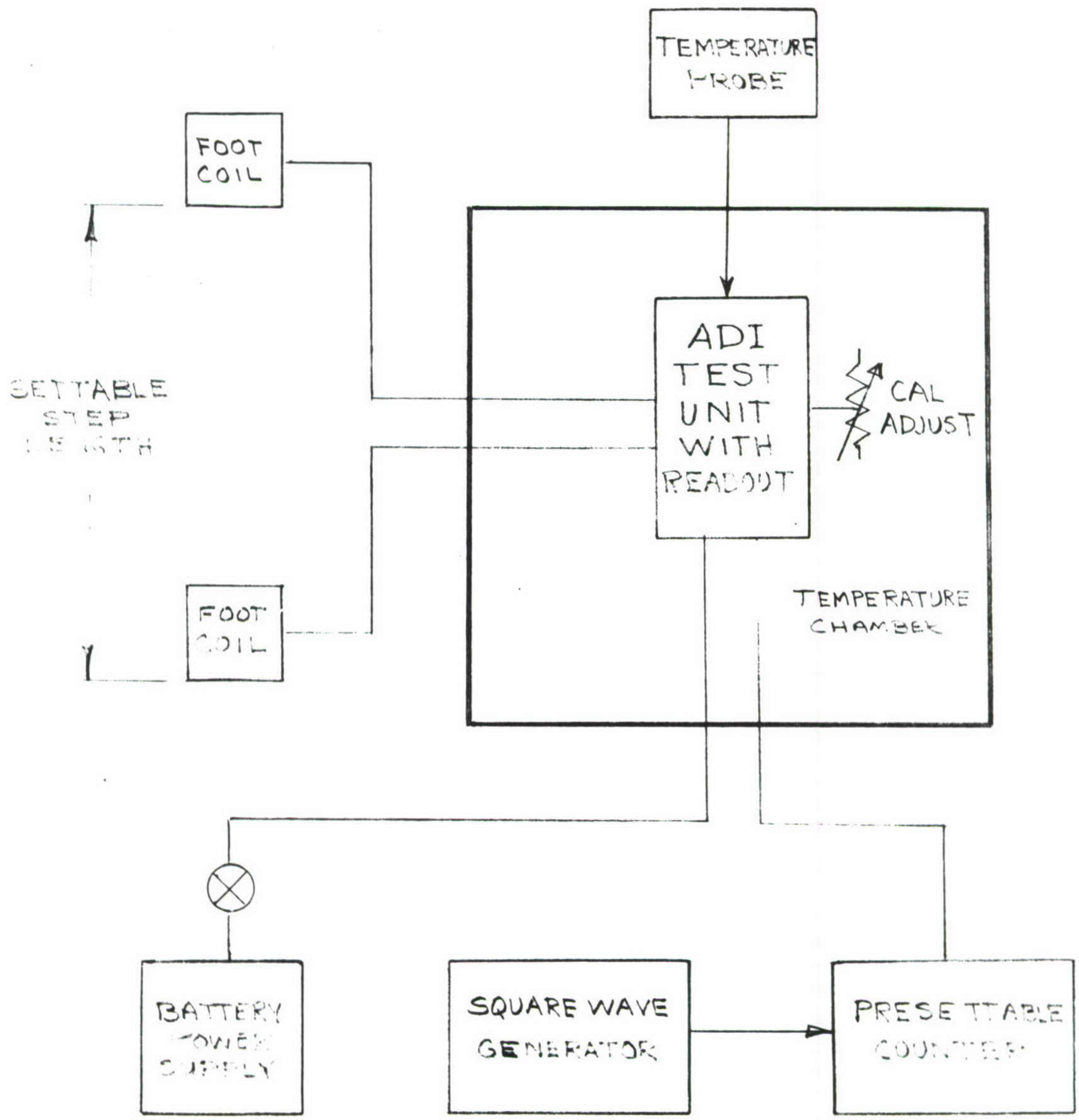

FIGURE 3-3. Temperature Test Set up

distance readout varied to some degree with temperature. This variation was greater than ± 2-1/2% over the temperature range of $0^{\circ}F$ to $115^{\circ}F$.

The unit was taken out of the oven and an investigation was made to determine where the contributions to the change occurred. This was done by using localized heating to isolate individual components which caused temperature sensitivity. It was found that several germanium diodes in the receiver cube root circuitry were contributing to the variation. These were replaced with hot carrier diodes to reduce the effect of leakage as a function of temperature. The unit was then placed in the oven again and temperature runs were repeated. The results showed that the temperature variation was reduced to ± 1-1/2% over the temperature range of -25 to $+115^{\circ}F$. Since other factors usually associated with temperature such as ground condition, would prescribe recalibration before this complete temperature range was encountered, accuracies within 1% would be achieved for any anticipated field environment.

In order to determine whether any other operational limitations would occur at greater temperature extremes exploratory runs were made at $-40^{\circ}F$ and $140^{\circ}F$. At $-37^{\circ}F$ the counter readout was observed to miss some counts. Upon increasing the temperature a few degrees the readout would count properly. No other malfunctions were observed.

3.3 Operational Test

The ADI brassboard and the three ADI prototype units were tested operationally by walking them over a measured course and observing the accuracy attained. The course was marked off at 200 meters with a mark also at 100 meters. It was laid out on a roadway adjacent to the Westinghouse Facility. The roadway provided a good straight line reference in order to eliminate contributions of additional distance from non straight line walking. Tests of all units were started with calibration "walks". These consisted of walking the 200 meter course in both directions noting

the readout distance at both 100 meters and 200 meters for both directions. Next the indicated calibration correction was set in and the course was rewalked in both directions several times using a different step length for some of the walks. The results were recorded for each walk. A check on the calibration accuracy was also made by setting the cal control to each limit and walking to determine that the indicated amount of correction would readout.

In addition to the walk test over the measured course a comparison check was made between units by walking a prescribed course through the building involving 9 90° turns. The distance indicated was 275 meters.

Results of the 200 meter walk tests showed that more than half of the walks had a readout of exactly 200 meters. The remainder of the walks had a deviation of ± 1 meter. Since one meter deviation in 200 meters represents 1/2% error all units provided better then one per cent accuracy during the walk tests. The calibration control limit checks gave results of almost perfect agreement between the cal offset value and the deviation of the readout for the distance walked. The comparison check between units, over the 275 meter course through the building, showed an agreement of better than 1 meter.

4.0 RELIABILITY

The Automatic Distance Indicator (ADI) circuit functions are similar to those of the automatic step length (ASL) portion of the AN/PSN-7. The similarity between the mechanization of the ADI and the ASL functions provides a good basis for making a reliability estimate for the ADI from PSN/7 reliability experience.

To obtain an estimate of reliability for the ADI the various portions of the ADI were compared with their counterpart in the PSN-7. The fractional part of the PSN-7 system represented by the ADI was then determined. The fractional part of the PSN-7 represented provides the factor to convert the reliability figure into an estimate for the ADI.

The PSN-7 contains 8 printed circuit boards. The ADI has 4 printed circuit boards which are comparable complexity-wise to 4 of the PSN-7 boards on nearly a one to one basis. The receiver/ cube root boards of the two systems are almost the same, the power supply and transmitter boards are of comparable complexity to those of the PSN-7 and the processor board is similar to a PSN-7 logic board. The 4 printed circuit boards of the PSN-7 which are similar to the ADI boards represent half of the PSN-7 printed circuit portion and 30% of the whole system. The control and read-out portion of the PSN-7 is about 10% of the total system and twice the complexity of the control and readout portion of the ADI system. The boot antenna portions of the two systems are essentially equal and this portion comprises 10% of the PSN-7. The battery and interwiring of the ADI is about half that of the PSN-7 and represents about 5% of the system. The principal differences between the two systems aside from 4 more PC boards and a more complex control and readout function is that the PSN-7 contains a compass unit and the ADI does not. The compass represents approximately 15% of the PSN-7 system.

A tally of the above percentages of the PSN-7 for which the ADI is comparable is given below:

COMPARED PART	% OF PSN-7
4 PC boards	30%
1/2 Control and Readout	5%
1 Boot Antenna System	10%
1/2 Battery and Interwiring	5%
TOTAL	50%

The total percentage indicates that the ADI system is about one half the complexity of the PSN-7. Using this factor and the computed MTBF figure of 7000 hours for the PSN-7 the ADI will have an estimated MTBF of 14,000 hours.

5.0 COST ESTIMATE

An ADI production cost estimate was made for a 1000 lot production. The estimate was based on budget estimate figures. Excluding escalation factors due to inflation the per unit recurring cost of an ADI system produced in 1000 lot quantities would be $1200.

6.0 CONCLUSIONS

The objectives of this program have been achieved. The goals for performance, size and weight (1% accuracy, .033 cu. ft. and 3 pounds) have been attained. In addition, should the favorable trend in battery industry developments continue, the ADI has been designed to be easily changed over to use batteries which will have a greater temperature capability and significantly greater life. The ADI design emphasizes display readability and a display larger than generally possible in such small systems has been incorporated.

These provisions as well as those of high reliability, maintainability and simplicity of operation have been made within a framework of a producible low cost system.

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